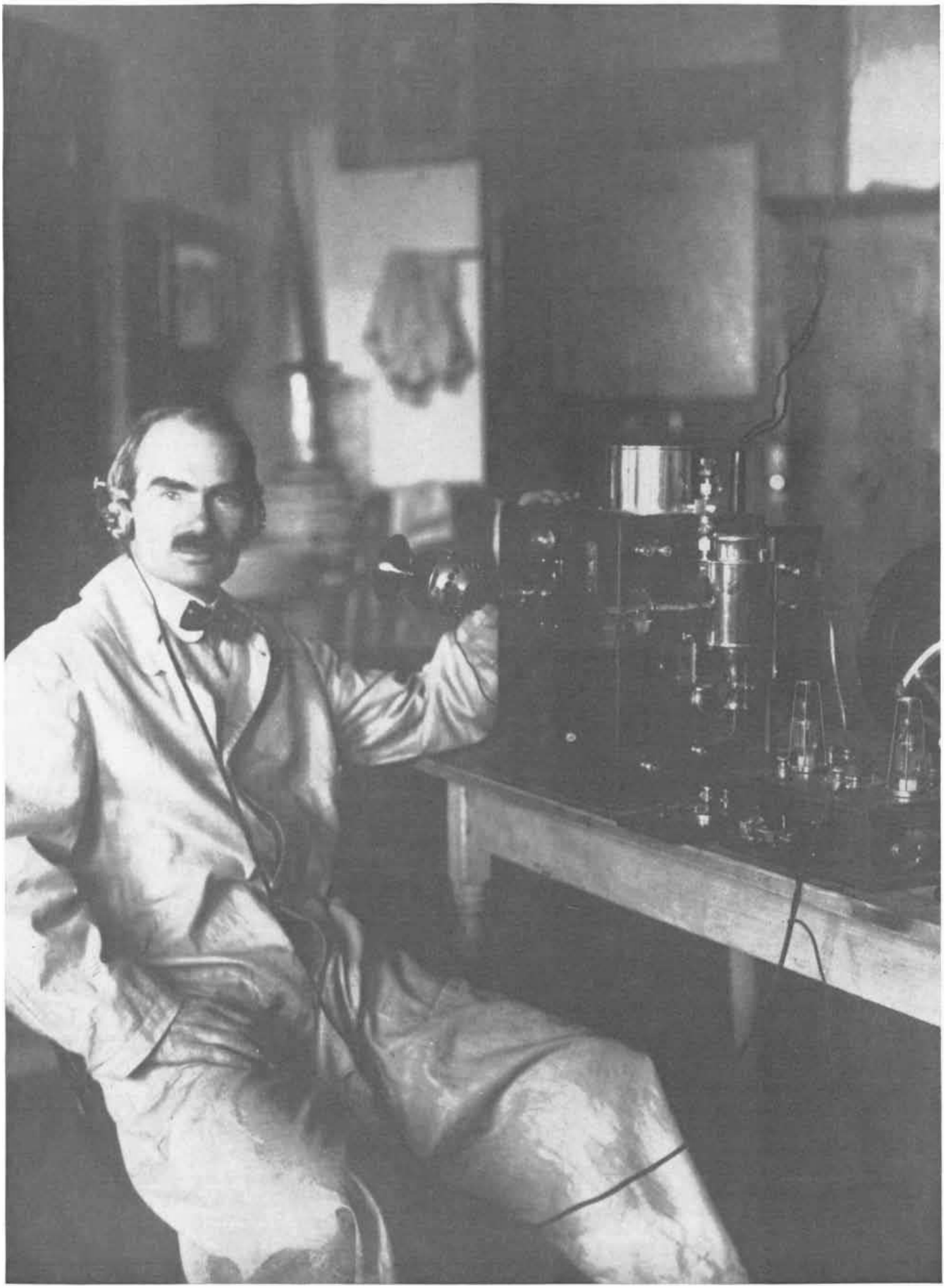


DE FOREST POSED with his wireless telephone set in 1907 or 1908. The large cabinet on which his hand rests houses the carbon-arc transmitter. The low cabinet at right is the receiver. Two tubes, apparently early grid-triodes, are visible under wire guards.

De Forest and the Triode Detector

He invented the three-electrode vacuum tube without understanding how it worked. His grid-triode was no great success as a detector, but it did eventually make modern radio and electronics possible

by Robert A. Chipman

The history of inventions is almost always clouded by claims and counterclaims and embellished with legend; often the inventor himself is a major contributor to the confusion. So it is in the case of the thermionic triode, which Lee De Forest invented in 1906 as a detector of wireless-telegraph signals. The triode, a three-electrode vacuum tube, was a truly seminal creation. As a detector, amplifier and oscillator it became the foundation of modern radio, and with its derivatives it dominated electronic technology for 50 years.

Most of what has been known about the invention of the triode comes from De Forest himself. Until his death in 1961 he told and retold stories about his invention, but in his speeches and writings De Forest was more a poet than an engineer or a scientist; there is often only a superficial relation between his recollections and the actual sequence of events. Only by interpreting De Forest's lively accounts in the light of independent evidence can one hope to construct a realistic description of his experiences in the early days of radio and of his processes of technological creation. Those processes turn out to have involved much imitation and self-deception, along with large measures of ingenuity, persistence and good luck.

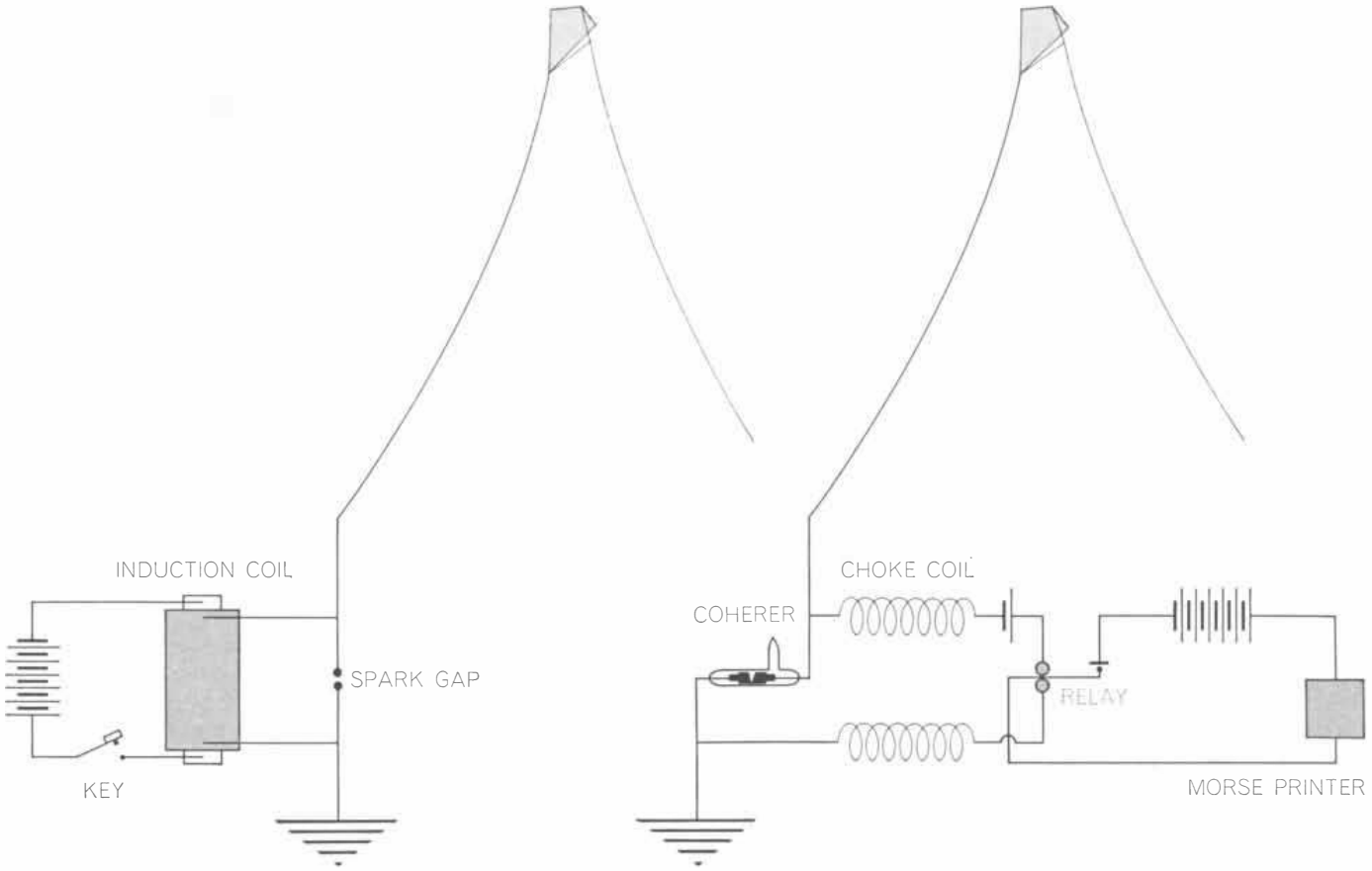
Lee De Forest was born in 1873 in Council Bluffs, Iowa, and grew up in Talladega, Ala., where his father was the principal of a school for Negroes. Before he was 16 the boy had gone on record as intending to be an inventor, and his pursuit of that ambition was facilitated by a remarkable circumstance: a wealthy ancestor had endowed a scholarship at Yale University for young men named De Forest. Lee received his bachelor's degree from Yale's Sheffield Scientific School in 1896, and in spite of an undistinguished undergraduate record he went on to a Ph.D. in 1899. His dissertation was on the reflection of Hertzian, or electromagnetic, waves traveling on wire transmission lines—possibly the first Ph.D. thesis in the U.S. on a topic closely related to wireless telegraphy.

His determination to achieve fame as an inventor was undaunted by his failure to sell any of the many "inventions" (including games and bicycle gears, but no wireless equipment) he conceived while at Yale. "I aim at Tesla," he wrote in his diary in 1896. And to the question (in a college questionnaire) "If you weren't yourself, who would you prefer to be?" he answered, "Tesla." Nikola Tesla, the brilliant but erratic worker in alternating-current technology who had invented the induction motor, refused him summer employment in 1897. Whether for that reason or not, De Forest shifted his sights; he wrote in his autobiography: "From the first I had the one aim in view, to make my name at least rank with that of Marconi." (Later, on the occasion of his being awarded the Edison Medal of the American Institute of Electrical Engineers in 1946, De Forest showed further flexibility: "From early boyhood, Thomas A. Edison was my ideal, my living inspiration, my idol.")

It was Guglielmo Marconi, at any rate, whom the young man chose to challenge. Emerging from Yale at the age of 26, De Forest took a job with the Western Electric Company in Chicago. He was not, however, enthusiastic about selling his services to any employer. Quick fame and riches were his goal, invention his chosen road; soon he decided that wireless telegraphy would be his vehicle. The young Italian engineer Marconi was then moving from success to success, attended by worldwide publicity on an unprecedented scale. From wireless transmission across the nine-mile Bristol Channel in England in 1897 Marconi had progressed to 20-mile communication while reporting a regatta in the Irish Sea in 1898; he conquered the 33-mile English Channel in 1899, linked two British warships across 75 miles of open water in 1900 and in early 1901 established communication over a 200-mile path in southern England. At the end of that year he climaxed his work by receiving a signal transmitted across the Atlantic Ocean.

Inventors in those days seldom issued patent licenses to competitors on a royalty basis; De Forest knew that he could challenge Marconi in the wireless-telegraph business only by owning the rights to a transmitter-receiver "system" sufficiently different from Marconi's to be reasonably safe from lawsuits for patent infringement. Marconi's transmitter was based on the induction coil and the spark gap, with which Heinrich Hertz had produced electromagnetic waves in his pioneering experiments of 1886. Marconi's receiver was based on the fact, discovered by the French physicist Édouard Branly in 1890, that an electric spark has the power to change the resistance of loose aggregations of metallic powders at a distance. Marconi's "coherer" was a tube containing nickel and silver filings; placed in series with a battery, it allowed a current to pass whenever an electromagnetic wave emitted by the transmitter arrived [*see top illustration on page 95*]. To both the transmitter and the receiver Marconi added a vital contribution: good electrical connections to the ground and long, high wires as antennas.

Reviewing his studies of Hertzian waves at Yale, where he had worked with similar apparatus, De Forest decided to start by finding a substitute



EARLY MARCONI APPARATUS is diagrammed. At the transmitter (*left*) trains of sparks generated by the induction coil set up electrical oscillations in the antenna, which is held aloft by a kite. The resulting electromagnetic waves excite high-frequency oscillations in the receiving antenna (*right*); these signals cause the coherer to operate the relay, closing the circuit of the local battery and the code printer. The two "choke coils" in the receiver serve to isolate the antenna circuit from the relay and printer.

for Marconi's coherer as a detector. (He was not alone: the magazine *Electrical World* carried 28 news items on various versions of the coherer in 1900.) The coherer was insensitive; it was sluggish, permitting code transmission at less than half the speed of wire transmission lines, and it required extensive auxiliary apparatus. Morever, since it was inherently an on-off device, it could never be adapted to wireless telephony, which was already being contemplated. Detector research had the virtue of being inexpensive and requiring little space—no small advantages to a would-be inventor working during off-hours in his bedroom while earning $10 a week at a full-time job.

Searching the technical journals for some new detector principle, De Forest learned that three different German experimenters had described new detectors in which a telephone receiver was connected in series with a battery and with two metal electrodes separated by a thin layer of a conducting liquid such as water; the operation of a spark coil nearby produced a scratchy sound in the receiver. With financial and technical help from a fellow employee, Edwin H. Smythe, De Forest experimented with such arrangements for nearly a year. On September 1, 1900, he and Smythe applied for a patent on what he called a "Responder": a sandwich of two flat metal strips separated by a thin layer of liquid or of liquid-soaked porous material. The device was obviously simple and quick-acting, and there is no reason to doubt that it could detect wireless waves. Nevertheless, it was probably very insensitive; there is no trace of evidence that it was ever put to use in a communication system.

De Forest and Smythe next came on a report (perhaps in an article in *Electrical World* for May 18, 1901) of a paper presented to the French Academy of Sciences describing a "loud-speaking radio-phone," a detector capable of handling such strong signals that the dot-dash buzzing of a telephone was audible throughout a large room. The device resembled a Marconi coherer but the dry metal filings were replaced by a pasty mixture of silver filings and a powdered insulator such as sulfur in glycerine. Like the sandwich device, the French detector was actually an "anti-coherer": its resistance increased instead of decreasing in the presence of electric waves. After brief experimentation De Forest and Smythe applied in 1901 for a patent covering essentially the same device. Since De Forest applied the name "Responder" indiscriminately to this detector as well as to his first invention and even to similar inventions made later by other people, it is hard to tell from his writings how effective the various designs were. Apparently, however, the 1901 "goo" detector did work, if only sporadically.

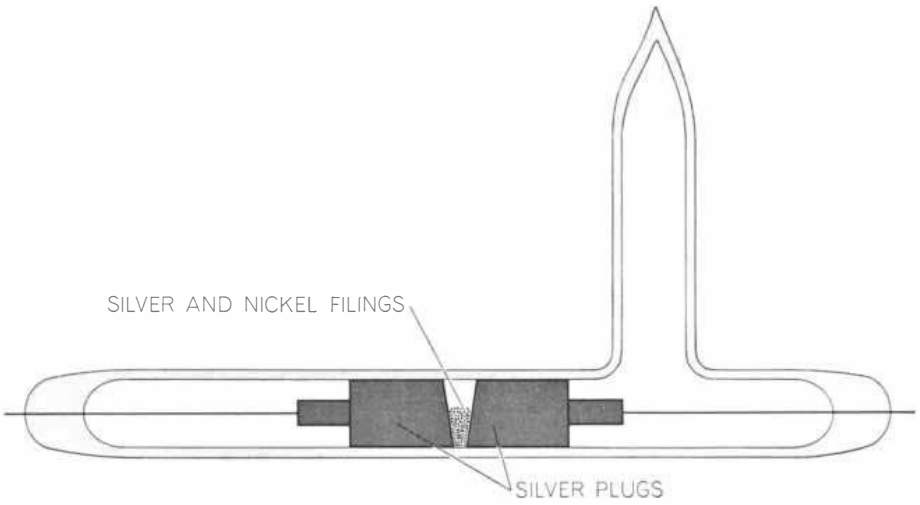
Whatever its deficiencies, it was the beginning of a "system," and any system was better than none. The *Western Electrician* for July 27, 1901, carried an article announcing "A New System of Space Telegraphy." The transmitter was a distinctly new type invented by Clarence Freeman, a professor at the Armour Institute; it produced a high voltage when a number of condensers that had been charged in parallel were suddenly switched into series connection. The receiver was the new Responder. The maximum transmission distance was reported as four miles. In his autobiography De Forest character-

istically referred to "this *first attempt* on the Great Lakes, indeed in all America, to send dots and dashes by wireless"—knowing full well that Marconi had demonstrated wireless over 35 miles to the U.S. Navy in New York in 1899 and that the U.S. Army Signal Corps and the Weather Bureau were communicating regularly over like distances!

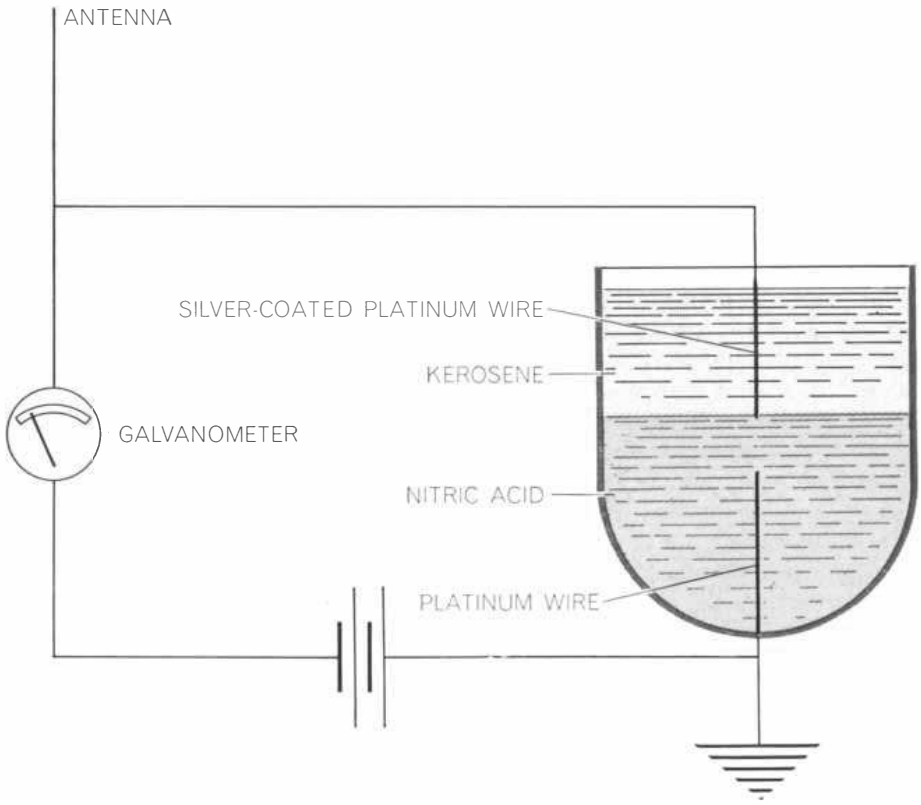
In less than three months there came an opportunity to test the system in direct competition with Marconi, who had contracted with the Associated Press to provide ship-to-shore reporting of the America's Cup races. De Forest made a deal to provide the same service for a rival news agency, the Publishers' Press. Fortunately for posterity the Navy detailed a lieutenant to check on the operation of the two systems; *Electrical World*'s account of the confrontation, apparently largely derived from his report, differs considerably from De Forest's later recollections.

Not having anticipated competition, Marconi had brought only his simplest equipment, with none of the elements he had recently developed to provide selective tuning of the receiver. Since De Forest's apparatus also lacked selectivity, both receiving stations responded equally well to both transmitters; when the transmitters were sending simultaneously, the signals received were unintelligible. When the De Forest and Marconi operators realized what was happening, they agreed to transmit alternately for five-minute intervals. That worked for a short time, until suddenly a third transmitter came on the air and created interference that prevented all further reporting of the races. De Forest never mentioned the intruder in his accounts of the event; he was probably unwilling to admit that anyone else in the U.S. knew enough about wireless telegraphy at the time to have attempted the feat. The third telegrapher later identified himself as G. P. Gehring, president of the American Wireless Telephone and Telegraph Company. His claims to have reported the races successfully were shown to be fictional, but the following year a subsidiary of his company did inaugurate the first daily wireless service in the U.S., between Catalina Island and the California mainland.

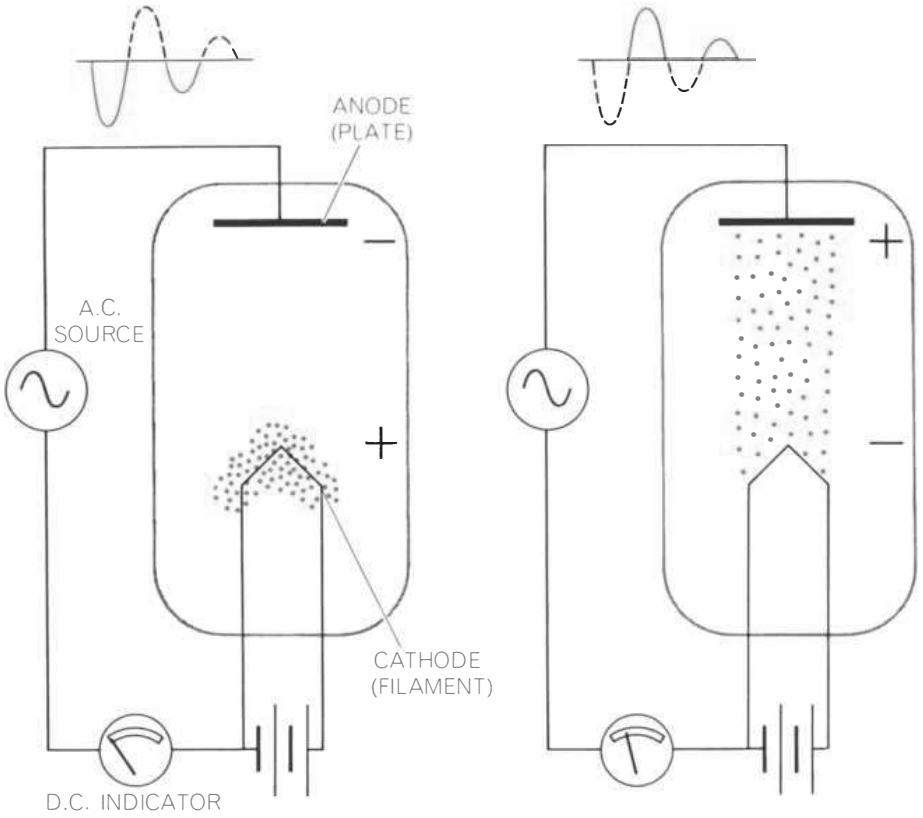
For his venture at the races De Forest had formed a small company with Freeman, Smythe and a former Yale classmate who provided most of the money. The idea of sharing with others his glory as an inventor, however, was intolerable to De Forest. During the races he had tossed Freeman's transmitter overboard (perhaps justifiably), and in the midst of his collaboration with Smythe on the Responder he had written in his diary: "Not for Smythe did I toil six years at Yale." Early in 1902 he interested a Wall Street promoter named Abraham White in financing his operations on a wider scale. De Forest became vice-president, scientific director and one-third owner of a new company capitalized at several million dollars, and his old associates were eased out. The company announced that it would construct coastal stations for communication with ships and inland stations to compete with Western Union and Postal Telegraph. Its tangible assets were the patents on the doubtful Responder and a record of wireless communication over seven miles at the races. Meanwhile Marconi had trans-



COHERER, as modified by Marconi, is here enlarged to twice its actual size. It detected signals because current flowed through the filings only when their resistance was lowered by a radio-frequency wave. The fragile glass vessel was lashed to a bone holder for convenience. An electric-bell mechanism vibrated the coherer to restore its sensitivity after each pulse.



ELECTROLYTIC DETECTOR patented by Reginald A. Fessenden in 1903 was a rectifier, although its mode of operation was not then understood. Electrochemical action converted high-frequency oscillations from the antenna into direct current that registered on the meter.



DIODE PRINCIPLE is shown schematically. The heated filament emits electrons (*colored dots*). The plate is connected to a source of alternating voltage. When that voltage acts in one direction, the plate is negative and the electrons are repelled (*left*). When the alternating voltage changes polarity, the plate is positive, electrons go to the plate and a current flows (*right*). An alternating-voltage input therefore can yield a direct-current output.

mitted thousands of words from England to a ship 1,200 miles at sea. *Electrical World* commented: "We continue to be regaled with newspaper accounts of experiments that are inferior to what Marconi achieved three years ago."

For the next five years De Forest enjoyed a great deal of publicity, far more than any other American engaged in wireless telegraphy. Yet his technical contributions during that period were minute and his commercial success was nil. His company did build more than 100 wireless stations in the East and Middle West, but they were primarily for the purpose of stock promotion; as *Scientific American* put it in 1907, they seemed to serve only to "educate the masses" and not to send messages. De Forest did obtain more than 25 patents during the period but not one proved to have contemporary commercial value. It is doubtful that any of the devices he patented were put to use in the company's stations.

The detector remained De Forest's big problem. The Responder could not be counted on even for a successful promotional demonstration; when De Forest exhibited his system to the Signal Corps in 1902, his detector was a sensitive anticoherer invented by an Italian naval officer and used by Marconi in his first transatlantic reception. In 1903 De Forest began installing in his company's stations an electrolytic detector similar to the one just patented by his American arch-rival Reginald A. Fessenden [*see bottom illustration on preceding page*]. Since the detector employed metal electrodes and a conducting liquid he referred to it as "our new Responder" until court injunctions and fines stopped him in 1905.

Without title to any adequate detector, the company dared not operate its stations commercially for fear of further punitive court action. His partners blamed De Forest and forced him out of the company. Again without funds and thrown back on his own resources, De Forest decided that a new and more brilliant future lay in wireless telephony rather than telegraphy. The Danish inventor Valdemar Poulsen was already successfully transmitting voice signals by wireless, generating with his patented electric arc the continuous oscillations required for telephony. De Forest modified the transmitter slightly, but he still needed a noninfringing detector.

He found the detector clue he needed in a two-electrode vacuum tube for which John Ambrose Fleming, a professor at the University of London and a consultant to Marconi, had received British and U.S. patents in the fall of 1905. The principle on which Fleming's invention was based had been discovered, but not utilized, by Edison about 20 years earlier. Edison noticed that if he placed an extra metal-plate electrode near the filament inside an incandescent lamp, connected to the positive side of the filament, an electric current flowed across the space between filament and electrode. No such current flowed if the plate was connected to the negative side of the filament. The explanation, provided by the British physicist O. W. Richardson in 1903, was that negative electrons were being emitted by the heated filament and were attracted only to a positive electrode. Fleming, who had been a consultant to Edison's British firm and had published papers on the "Edison effect," was the first person to understand clearly that wireless signals could be detected by this "rectification." In 1904 he saw that his Edison-effect lamps could rectify signals by acting as "valves."

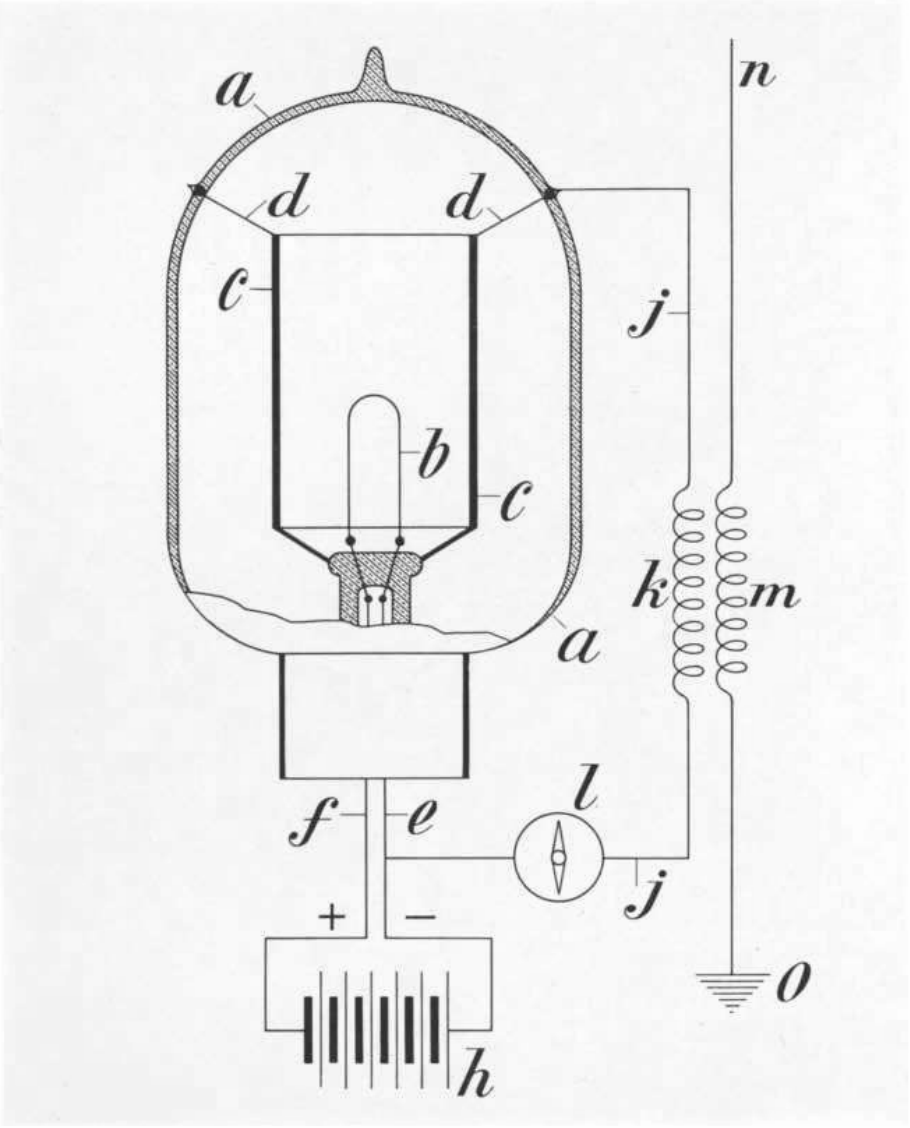
A dot or dash from any of the spark transmitters consisted of a sequence of damped high-frequency oscillations [*see "a" in illustration on pages 98 and 99*]. No indicating meter or telephone receiver could follow the rapid positive-to-negative reversals of the signal oscillations; nor could they respond to an average value, because the average value was zero. If, however, a distortion could be created by rectification so that responses to the portions of the oscillation patterns above and below the base line were not identical, then the average would no longer be zero. The lightly constrained current meter would accumulate impulses from successive trains of waves, being deflected more for a dash than for a dot; the diaphragm in the telephone receiver would vibrate once for each wave train, giving a long buzz for a dash and a short one for a dot. Fleming's valve produced a distorted response by "unilateral conduction," passing a current only during the positive portions of each incoming wave [*see "b" in illustration on pages 98 and 99*].

The Fleming valve was manufactured in small quantities beginning in 1905 and installed in many Marconi wireless stations during the next seven or eight years. As a detector it played an unimportant role in wireless communications, but it was certainly the first radio vacuum tube and it was of prime importance as an antecedent to the triode. As

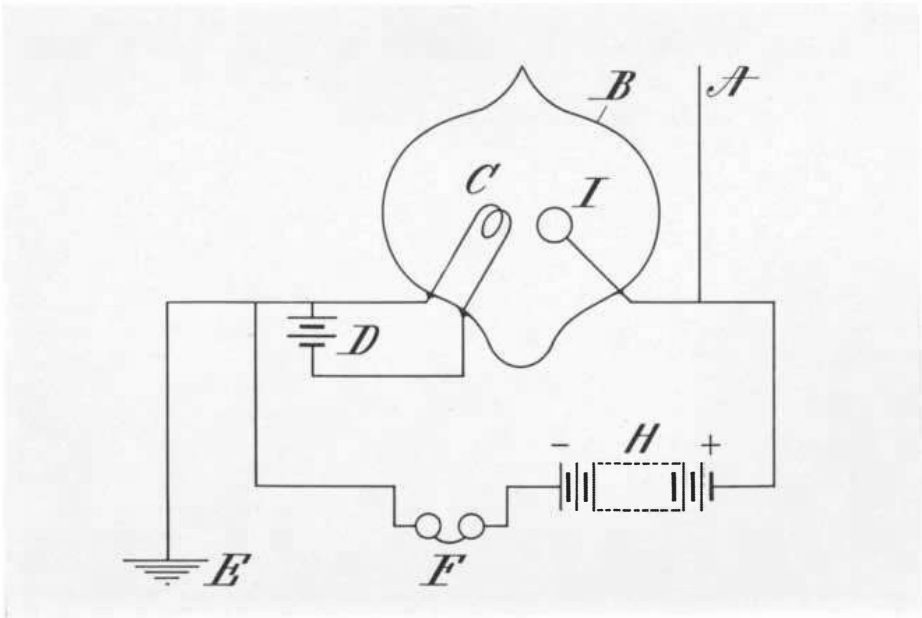
he read about Fleming's new detector De Forest immediately saw two ways in which its circuit differed from the one he had been using with other types of detectors. It had a galvanometer instead of a telephone receiver as an indicator and it had no battery in the indicator circuit. De Forest applied in January, 1906, for a patent covering these modifications and some other changes and in May for a patent on the telephone and battery only [*see bottom illustration at right*]; the patents were granted in June and November respectively.

Today De Forest's circuit would be classified as a "forward-biased thermionic diode rectifier"—"forward-biased" because the extra battery maintains a positive voltage on the plate electrode, "thermionic" because electrons are emitted from the filament electrode by heat, "diode" because there are two electrodes. On October 26, 1906, De Forest delivered a long paper to the New York section of the American Institute of Electrical Engineers in which he advanced for the first time the two broad claims about his diode that he was to reiterate for half a century as part of his legend of the invention of the triode. Both claims are technically unjustifiable; taken literally, they would be evidence of a scientific naïveté remarkable in an active inventor only seven years away from a Ph.D. in physics. It is more charitable to assume that the claims and their supporting narrative were developed as defenses against a potential suit for infringement of the Fleming patent. (The suit did come, nine years later, and was won by Marconi, who owned the patent.) Whatever its purpose, De Forest's oft-told tale must be reckoned with if one is to understand the reasoning and the experimentation that led to the triode.

De Forest contended first of all that his invention of the forward-biased diode did not stem from his knowledge of the Fleming valve but was a logical outcome of work he had begun in 1900. In that year he had seen the light of a gas lamp momentarily dimmed by the sparking of a nearby induction coil. He soon found that the dimming was caused by sound waves from the sparks, not by electric waves, but "there yet remained the firm conviction that in the heated gases surrounding incandescent electrodes there must nevertheless exist a response, in some electrical form, to high-frequency electrical oscillations." (De Forest had not mentioned this "conviction" in reporting the gas-lamp observation in *Electrical World* in 1902.)



FLEMING VALVE, or thermionic diode, is shown as illustrated in the patent of 1905. Electrons emitted by the filament (*b*) moved to the cylindrical plate (*c*) when the plate was positively charged by the signal from the antenna (*n*). The indicator was a meter (*l*).



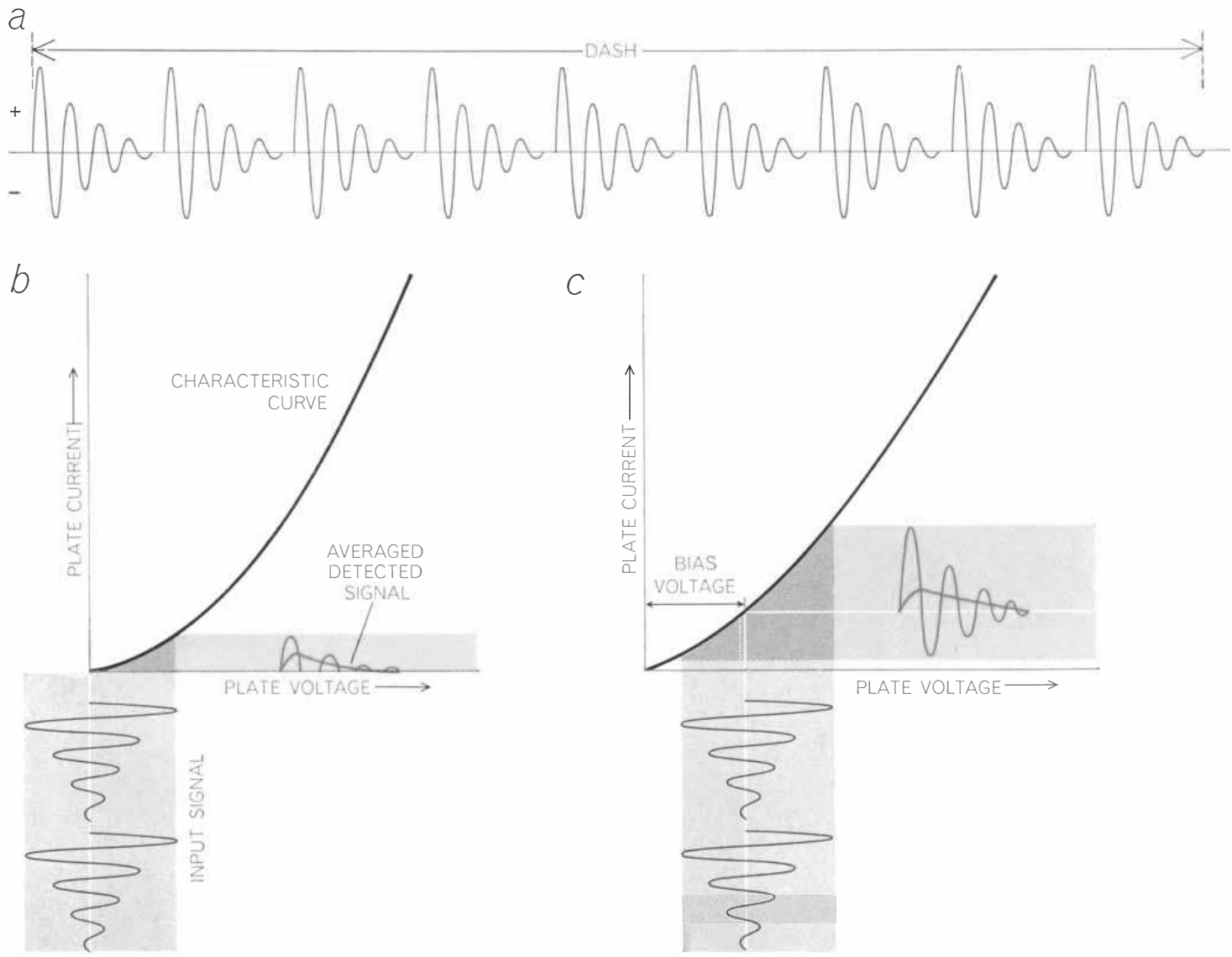
DE FOREST'S DIODE of 1906 had a telephone receiver for an indicator and added a battery (*H*) to the plate circuit. The battery served to maintain a positive "bias" on the plate.

He had followed up the idea by developing detectors in which the ends of platinum wires were placed in the flame of a Bunsen burner. The recurring theme in the patent applications for these devices in 1905 and 1906 was that the wireless signal oscillations were being applied to "a gas maintained in a state of molecular and ionic activity," "a sensitive gaseous conducting medium" or "a heated gas."

De Forest made the transition from gas flame to thermionic diode in these words: "Inasmuch as the gases ionize more readily at lower heats and are in their most mobile, delicate and sensitive conditions in vacuum, it seemed to me certain after experiments with the flame that the attenuated and ionized gases around an incandescent filament would undergo very considerable changes when subjected to hertzian oscillations." This is somewhat lyrical but it is illogical and technically meaningless. It epitomizes De Forest's lifelong aversion to the precision of technical language. His staunch loyalty to the mystical idea of a "sensitive gaseous conducting medium" kept him from appreciating the fundamental electronic basis of the thermionic diode and triode until long after it was generally accepted.

In his second claim De Forest insisted that the addition of a battery in the plate circuit, with the positive terminal to the plate, converted the detector to a mode of operation totally different from the rectifying action of the Fleming valve. It was now, he said, "a so-called 'trigger' or genuine relay." He had in mind the old coherer, which was in fact such a device: the low-power wireless signal "triggered" a change in the resistance of the metal filings and the local battery then supplied a much larger power to the indicator circuit.

It does seem plausible, as one looks at De Forest's patent drawing, that the antenna-to-ground wireless signal across the diode might change conditions inside the bulb and so trigger a sizable current from the battery through the diode and the telephone. Analysis makes it clear that this does not happen, and that the device is purely a rectifier. The battery does no more than maintain a bias voltage on the plate, shifting the diode's action from rectification by unilateral conduction to rectification by



RECTIFICATION changes an oscillating high-frequency signal into a detectable direct-current signal. In wireless telegraphy the signal from the antenna is in the form of sequences of damped oscillations (*a*). The detection process is shown graphically in the lower diagrams; the "characteristic curve" shows how input voltage is related to magnitude of output current. In the Fleming valve only the positive half of each wave applied to the plate produces an output current, which is then "averaged" by the mechanical inertia of the diaphragm or meter needle (*b*). In De Forest's diode a "forward bias voltage" keeps the plate always positive; the asymmetric relation between input voltage and output current distorts the output to yield a detectable averaged signal (*c*). In the triode detector the signal is impressed not on the plate but on a grid of closely spaced wires placed near the filament, between it and the

"curvature of the characteristic." The response to the positive portions of the signal is greater than with zero bias but is partly offset by a reverse response to the negative portions [*see "c" in illustration on these two pages*].

The fact is that a thermionic diode generally detects small signals best when it has no bias or even a small negative bias; Fleming had chosen the latter condition by connecting his plate electrode to the negative side of the filament. (Crystal or electrolytic detectors, which also work by rectifying, do often perform best with positive bias.) Moreover, in all simple rectifying detectors, whether they are supplied with forward or reverse bias or with no bias at all, all of the signal power that reaches the telephone or other indicator comes from the input signal at the antenna.

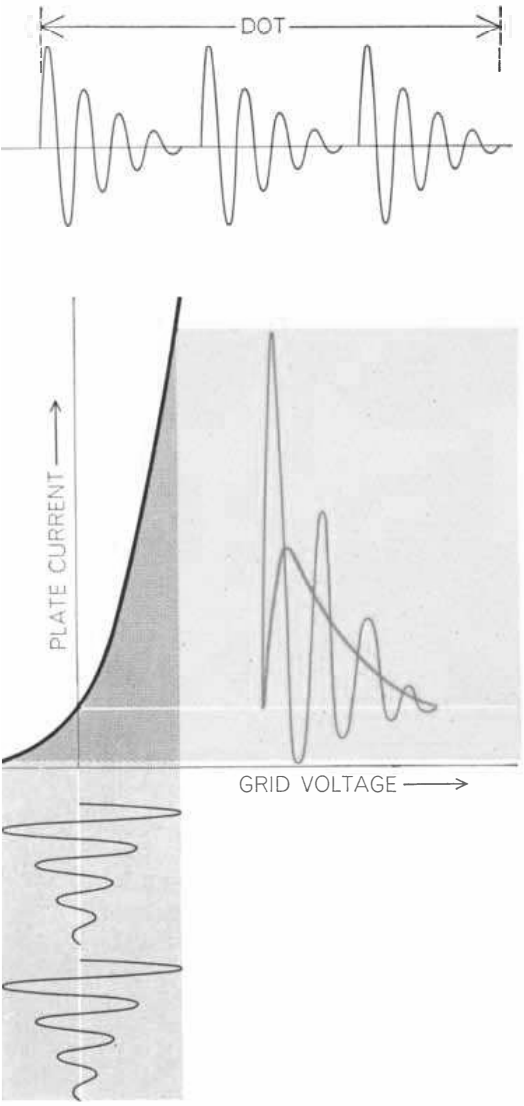


plate. If the grid is properly designed and located, the plate current is more responsive to signals on the grid than it would be to signals on the plate: the characteristic curve is steeper. For this and other reasons (*see illustration on next page*) output power can be greater than input power (*d*).

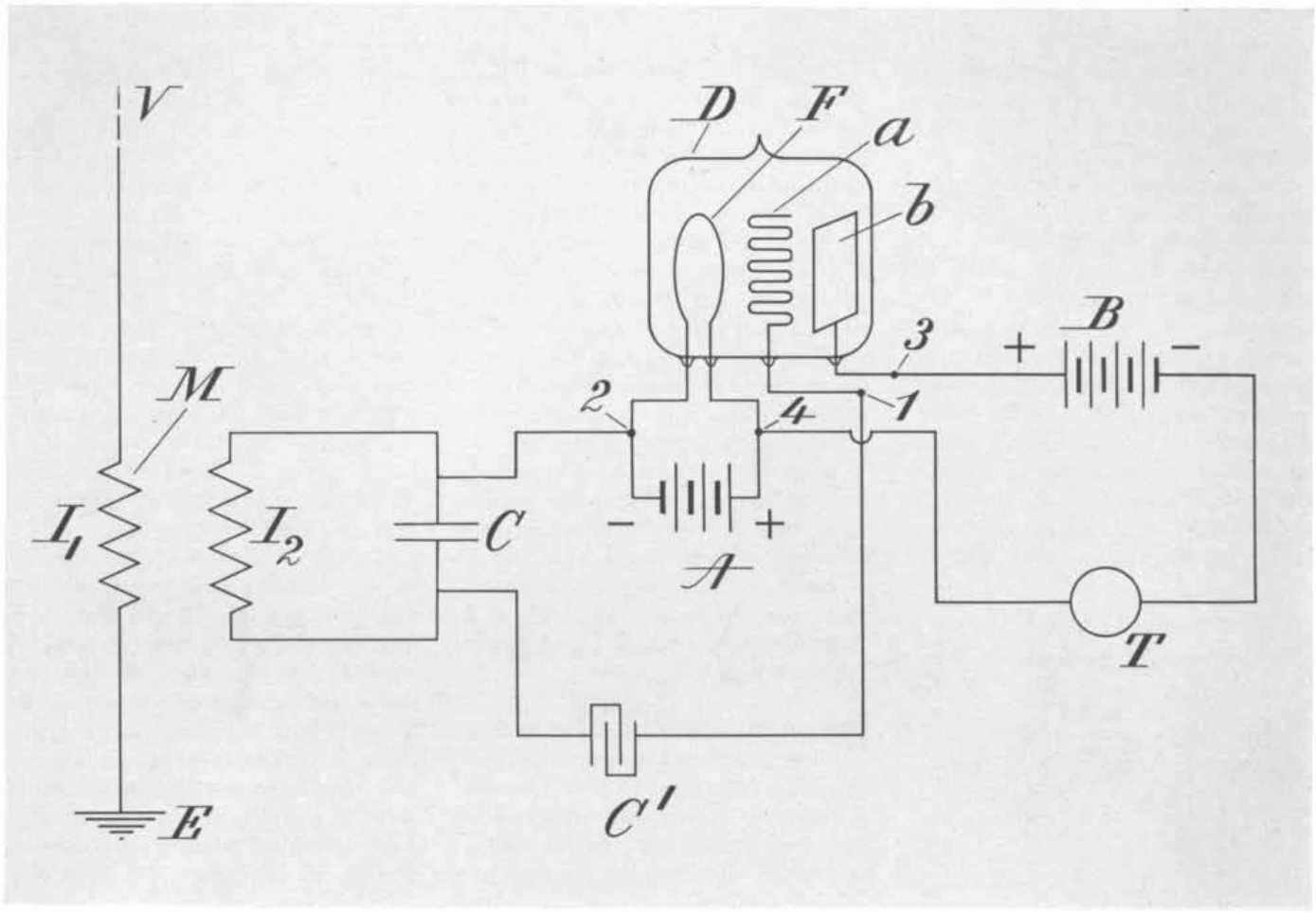
The forward-biased thermionic diode, then, had no practical value; it was never put to commercial use. It was of historical significance, however; in spite of the fallaciousness of De Forest's reasoning it seems clear that he was indeed pursuing the elusive "trigger action" when he created the triode late in 1906. He said later that he was also trying to overcome an apparent weakness of the diode circuit: a portion of the wireless signal from the antenna was able "to pass to earth through the telephone and battery circuit instead of concentrating ... upon the ions between the plate and filament." Again the idea seems to make sense, but De Forest had described in his very first patent application how the detector could be isolated from the battery circuit by small choke coils as in Marconi's early receiver [*see top illustration on page 94*].

Driven by wishful thinking and the urge to solve a nonexistent problem, De Forest experimented with a number of different electrode configurations that would allow the wireless signals to "trigger" the "sensitive gaseous conducting medium" and would also keep them out of the telephone-battery circuit. He applied for patents on a variety of such designs during 1905 and 1906. All of them were "triodes": they each had a third electrode of some kind, to which the incoming signal was connected instead of being connected to the plate. All these models were highly inefficient, although they may have detected very strong signals. Finally De Forest decided he got the best results with an extra electrode in the form of an open grid of fine wire located between the filament and the plate. He filed a patent application for this grid-triode detector in January, 1907, and received his patent in 1908. The input was connected to the grid and the telephone receiver was actuated by variations of the current in the plate circuit [*see illustration on next page*].

De Forest's legend of the triode insists that each step in his experiments brought a marked improvement and that he immediately found the grid-triode to be the most sensitive device of all. The fact is that all the versions except the final grid-triode must have been extremely poor detectors. The impression, implicit in popular accounts and nurtured by De Forest, that the grid-triode was immediately recognized as a miraculous achievement is also contradicted by a number of facts. In 1908 one of De Forest's assistants wrote in a *Modern Electronics* article that "the audion [a name De Forest applied indiscriminately to all his diodes and triodes] in its present form is quite unreliable and entirely too complex to be properly handled by the usual wireless operator." In 1910 tests at the National Bureau of Standards gave a somewhat more favorable verdict: the triode was declared to be about 50 percent more sensitive than the electrolytic detector, with the crystal rectifier and other detector types only slightly behind. In practical communications a superiority of 50 percent is barely perceptible, but De Forest found the result pleasing enough to proclaim it in his advertising years later.

Modern measurements on some of the early triodes show that as detectors they were not much better than diode rectifiers. If De Forest had ever experimented with variations in the size, shape and spacing of the electrodes, he could have achieved great improvements in performance, but he seems to have considered the 1906 audion essentially a completed invention, and he made no contribution to the important changes in its design that eventually occurred. As late as 1916, when a would-be competitor marketed a triode of radically different but incredibly inefficient geometry, De Forest's uncritical response was to manufacture a duplicate of the inferior device, even though Western Electric and the General Electric Company had by that time developed greatly improved tubes based on better understanding of fundamental design principles.

There is ample evidence that the early triode was no great commercial success. During 1909 and 1910 De Forest manufactured and sold a variety of radio-equipment products, but in his advertising he mentioned the audion either not at all or only as one among many minor items. In 1912 he allowed his British patent to lapse for nonpayment of a $125 renewal fee. W. J. McCandless, who in his New York City plant manufactured all the triodes produced in the U.S. until 1913, reviewed his early records some years ago. It appears that he had turned out only about 200 to 300 triodes a year up to 1910, after which the annual output rose to about 600. These figures represent a very small percentage of the estimated number of commercial and amateur wireless stations in the country during those years, indicating that other devices, primarily the crystal and electrolytic detectors, were far more popu-



TRIODE-DETECTOR CIRCUIT, redrawn from De Forest's patent application of 1907, shows a grid (*a*) between the filament (*F*) and the plate (*b*). De Forest's grids did not provide much increase in power of the kind described on the preceding page. He did find, however, that connecting condenser *C′* in the circuit improved the tube's sensitivity. In 1914 Edwin H. Armstrong showed that this improvement was the result of a charge-storage effect that increased the variations in the voltage delivered to the grid.

lar than the expensive and short-lived triode.

In summary, the first stage in the history of the triode vacuum tube, in which it was a detector of radio signals, is entirely De Forest's. He invented the device in the cut-and-try sense of the word and with no scientific understanding of what he was doing. All of the few thousand triodes produced in this country before 1913 were manufactured under his authority and to his designs. Yet to most of the wireless operators of the time the triode was just another detector, sometimes better but often worse than other detectors. The invention of the triode detector as such would never have brought De Forest the lasting fame or the riches he craved.

The second stage of triode history began in 1912. For years telephone engineers had been seeking a "repeater," or amplifier, for voice signals; without such a device it appeared that transcontinental telephone service might never be possible. Always quick to sense a commercial possibility, De Forest filed a patent application as early as June, 1907, for a "System for Amplifying Feeble Electric Currents." The circuit included triodes but they served only as detectors, and the device did not actually amplify.

The discovery that the triode could perform the function of amplifying voice-frequency signals was made independently by De Forest in 1912 and by a number of other scientists and inventors in at least three countries during 1912 and 1913. Several of these experimenters made two additional discoveries. The first was that triode circuits could amplify high-frequency radio signals as well as voice frequencies; the second was that if the output of an amplifier was fed back into its own input, the circuit could become a self-sustaining oscillator, or generator of electrical signals, and therefore a radio transmitter.

The U.S. courts took more than 20 years to decide who should be awarded patent priority for these valuable new triode circuit inventions. In 1934 they finally declared De Forest the winner, dating his inventions in the late summer of 1912. This decision established De Forest as the inventor not only of the triode as an assembly of parts but also of its principal applications; it is the justification for his eminent position among U.S. inventors.

The discovery of the amplification and oscillation functions of the triode marks the beginning of the modern age of electronics, but De Forest played no large part in the development of that age. Major industrial laboratories took over, and in less than three years De Forest's crude, erratic and gassy triode, which had changed little since 1906, was transformed into a variety of reliable, efficient and powerful forms so useful for communication that more than a million tubes were manufactured for military purposes in World War I. De Forest's patent position and his production facilities earned him a modest portion of the war contracts, but he made no further creative contributions to the development of his great invention.